Evaluation of Construction and Plugging Procedures for Well 353XC-35R in the CTV-Elk Hills Monterey Formation 26R Class VI Project

This well construction and plugging evaluation report for the proposed Carbon TerraVault (CTV)-Elk Hills Class VI geologic sequestration (GS) project summarizes EPA's evaluation of several related activities associated with the construction and plugging of the 353XC-35R injection well that CTV will use to inject CO_2 into the Monterey Formation 26R Reservoir. This review also identifies preliminary questions for the applicant. CTV provided information about the construction of Well 353XC-35R in a document titled Well Construction, Operating, and Plugging (COP) Details, dated May 31, 2022 and in a confidential file entitled Injection & Monitoring Well Schematics, Elk Hills 26R Storage Project dated May 31, 2022.

CTV plans to inject CO_2 into the Monterey Formation 26R Reservoir via four injection wells, including one existing well (373-35R) and three wells to be constructed (345C-36R, 353XC-35R, and 363C-27R). This construction and plugging report is specific to a Class VI permit for well 353XC-35R.

Injection Well Construction

Well 353XC-35R will be a Class VI well that will be drilled by CTV for the purposes of CO_2 injection. The COP contains the following brief construction details regarding the construction of 353XC-35R:

- Well designs will be sufficient to withstand all anticipated load cases including safety factors.
- Multiple cemented casing strings will be installed to protect shallow formations from contacting injection fluid.
- All the casing strings will be cemented in place with a volume sufficient to place cement to surface using industry-proven recommended practices for slurry design and placement.
- Cement bond logging (CBL) will be used to verify presence of cement in the production casing annulus through and above the confining layer.
- Mechanical integrity testing (MIT) will be performed on the tubing and the tubing/casing annulus.
- Upper completion design that enables monitoring devices to be installed downhole, cased hole logs to be acquired and MIT to be conducted.
- All wellhead equipment and downhole tubulars will be designed to accommodate the dimensions necessary for deployment of monitoring equipment such as wireline-conveyed logging tools and sampling devices.
- Realtime surface monitoring equipment with remote connectivity to a centralized facility and alarms to provide continual awareness to potential anomalous injection conditions.
- Annular fluid (packer fluid) density and additives to mitigate corrosion.

The COP states that well materials will be compatible with the CO_2 injectate and will limit corrosion, including the use of: tubing constructed of L-80 or other corrosion resistant alloy based on the injected CO_2 specifications; a packer made of corrosion resistant alloy and hardened rubber; casing constructed with L-80 steel (or other corrosion resistant alloy); CO_2 compatible Portland cement; and a wellhead constructed of stainless steel or other corrosion resistant material. All materials will meet API specification standards, which is consistent with EPA guidance.

Tables 1 and 2 of the COP present information about the casing and tubing specifications, respectively, and Table3 describes the packer specifications. The data presented in Tables 1 through 3 are consistent with the well diagram.

The surface and downhole pressure gauge and logging tool specifications detailed in Tables 8-14 of the quality assurance surveillance plan (QASP) are consistent with the well construction equipment and surface and subsurface temperature and pressure conditions.

The applicant provided a well diagram for Well 353XC-35R in the confidential file of Injection & Monitoring Well Schematics. While the diagram is not reproduced here to retain confidentiality, an evaluation in the context of other information in the permit application is provided. Relevant geologic formation tops were noted on the wellbore diagram.

the well diagram figure indicates there is no USDW. This is acceptable at this point in the permit application review. Pre-operational testing will help confirm whether the surface casing is sufficiently deep to protect the lowermost USDW in accordance with 40 CFR 146.86(b)(2).

The San Joaquin and Etchegoin Formation tops, as depicted on the well diagram, are protected by cemented long string and intermediate casings. The depth of the Etchegoin Formation on the well diagram is consistent with information in the permit application narrative, and the depth of the Monterey Formation 26R Sands is within the range of depths reported on Table 1 of the narrative (4,828 to 7,827 ft TVD).

Multiple sources of anthropogenic CO_2 are being considered for the Elk Hills 26R Injection Project. These include the Elk Hills NGCC Power Plant as well as third party existing and proposed industrial sources in the Southern San Joaquin Valley area. However, no specific information about the CO_2 content or any impurities was provided in the COP. The applicant states that a suitable corrosion-resistant alloy will be selected and installed once the CO_2 stream impurities and impurity concentrations have been determined. (However, the applicant did not provide a pre-operational testing plan to test the compatibility of the injectate with well construction materials.)

Following the pre-construction measurement of the composition, properties, and corrosiveness of the injectate, the well construction materials and cement will need to be reviewed based on the results of these tests and prior to operation of Well 353XC-35R.

The permit application narrative (on pg. 2) notes that the "…continuously subsiding [San Joaquin] basin is a sediment filled depression that lies between the Sierra Nevada and Coast Ranges and is 450 miles long by 35 miles wide." The effects of subsidence on the mechanical integrity of injection wells has been cited as a concern in other California oil fields, and some operators have developed mitigation measures to relieve stress on the surface casing (e.g., via wellhead design that allows differential movement between the casings). Any design modifications to address the subsidence concern will need to meet the requirement that Class VI wells have cementing of the surface casing that extends to the surface.

Questions/Requests for the applicant:

- *Please include the conductor casing grade on Table 1.*
- *Please provide details related to the well's casing and cementing design to demonstrate that potential shallow compression, resulting from land subsidence, will not affect the integrity of the casing and/or cement.*

- *The depth of the bottom perforations for well 353XC-35R are below the deepest depth of the Monterey formation as reported on Table 1 of the narrative; please clarify.*
- *Please discuss the duration that free phase water is expected to be present at the beginning of the injection phase and the corresponding impact on tubing integrity. For example, please provide additional discussion regarding the study of this phenomenon, e.g., in existing, nearby CO_2 injection wells.*

Monitoring Well Construction

Schematics of the monitoring wells, including: the shallow monitoring well, 355X-26R (the Etchegoin Formation monitoring well), and the three Monterey Formation monitoring wells (341-27R, 328-25R and 376-36R) were provided in a confidential file with information on wells in the AoR. All of the monitoring wells have been drilled and completed. See the October 2022 Testing and Monitoring Evaluation for EPA's evaluation of these wells.

Injection Well Pre-Operational Testing

The COP for injection well 353XC-35R describes the proposed pre-injection (pre-operational) logging and testing activities to be conducted during drilling and installation of the injection well as required under 40 CFR 146.87(a), (b), (c), (d), and (e). CTV will notify EPA at least 30 days prior to conducting tests, and provide a description of the procedures, and will also provide EPA 48-hour advance notice should they want to be present during any of the testing. The tests described in the COP include the following:

- Deviation checks at intervals of approximately 120 feet during well construction
- Logging to be conducted during drilling of the well, including:
    - Dual induction laterolog
    - Spontaneous potential
    - Gamma Ray
    - Caliper
    - Compensated neutron
    - Formation density
    - Mud log
    - Acoustic cement bond log
- Mechanical integrity testing prior to injection/operation:
    - Internal standard annular pressure test (SAPT)
    - External temperature log
- Injectivity and pressure fall-off tests

Procedures are provided for the annulus pressure test, which will be run for a minimum of 60 minutes with measurements collected in 10-minute intervals. Pressure fall-off testing to assess injectivity and reservoir flow boundary distances/pressures, and to compare injection rates/pressures with results from computational modeling is also described. During pressure fall-off testing, the injection rate will be held high enough to produce pressure build up but not exceed the maximum operating pressure. A surface gauge at the wellhead and a downhole gauge set above the packer with real-time surface readout capability will be used for the pressure falloff test.

No detailed procedures for the other tests, including MITs, are included in the COP.

Objectives for Pre-Operational Testing

Based on the site characterization, AoR delineation modeling, and testing and monitoring evaluations, EPA has identified the following objectives for the planned pre-operational testing to address data gaps identified during the reviews. This information is summarized below (along with the planned tests that will address each data need that was described in the initial permit application materials submitted in November 2021) for reference and to clarify EPA's expectations for the updated materials that CTV must submit pursuant to 40 CFR 146.82(c) and 146.87.

Regional Geology and Geologic Structure

- Perform pressure build-up testing (anticipated testing method: pressure build-up test).
- Confirm the fracture pressure of the injection and confining zones (anticipated testing method: step-rate test in each zone using a representative fluid).

Geochemistry/Geochemical Data

- Establish baseline geochemistry for the Monterey Formation, as well as the Tulare and Etchegoin Formations for all analytes to be monitored during injection operations, per the Testing and Monitoring Plan (anticipated testing methods: various geochemical analyses).

Seismic History and Seismic Risk

- Establish baseline seismicity (anticipated testing method: existing seismic network/historic seismicity database).

Facies Changes in the Injection or Confining Zones

- Determine if there are any heterogeneities within the Monterey 26R injection zone that could affect its suitability for injection, including facies changes that could facilitate preferential flow (anticipated testing methods: pressure build-up test; planned and completed core, log, and seismic analysis).

CO_2 Stream Compatibility with Subsurface Fluids and Minerals

- Confirm the composition and water content of the CO_2 injectate as part of baseline sampling and verify that it will not react with the formation matrix (anticipated testing methods: various geochemical analyses, benchtop studies).
- Confirm that the properties of the CO_2 stream are consistent with the AoR delineation model inputs (anticipated testing methods: various geochemical analyses).
- Confirm that the analytes for injectate and ground water quality monitoring are appropriate based on the results of the geochemical modeling evaluation (anticipated testing methods: various geochemical analyses).

Confining Zone Integrity

- Collect baseline pressure data in the Etchegoin Formation to support upward confinement between the Monterey and shallower formations (anticipated testing method: pressure build-up test).
- Determine the porosity and permeability of the Reef Ridge Shale at the location of each of the 26R project wells (anticipated testing methods: core and log data during well drilling).
- Test for changes in capillary entry pressure of the Reef Ridge Shale due to reaction of the shale with the injectate (anticipated testing method: mercury injection capillary pressure).

Injection Well Construction

- Following the pre-construction measurement of the composition, properties, and corrosiveness of the injectate, review the well construction materials and cement in the context of the results of these tests (anticipated testing methods: various geochemical analyses).

Monitoring Well Pre-Operational Testing

No pre-operational well testing is described for any of the monitoring wells (i.e., the planned Upper Tulare Formation monitoring, Well 355X-26R in the Etchegoin Formation, or Wells 341-27R, 328-25R and 376-36R in the Monterey Formation) within the COP for Well 373-35R.

Demonstration of mechanical integrity will need to be conducted prior to injection operations; see the monitoring evaluation report for additional information.

Questions/Requests for the applicant:

- *Please describe in the Well Construction Plan the pre-operational testing procedures to be performed on the monitoring wells.*
- *Please provide MIT procedures for the temperature log.*
- *Please describe in the Well Construction Plan the pre-operational testing to confirm the compatibility of the well materials with the CO_2 stream and the formation testing required at 40 CFR 146.87 (e.g., core analyses, water quality geochemical testing, step-rate testing, and pressure build-up testing).*
- *Please check and correct step 4 of the annulus pressure test procedures. There appears to be an inadvertent repeat of the sentence about measurements at 10-minute intervals.*

Injection Well Plugging Plan

Plugging details for Well 353XC-35R are provided in Table 6 of the COP, which contains Before plugging the injection well, CTV will determine the bottom-hole pressure needed to successfully squeeze cement for plugging operations. At least one external MIT will be conducted prior to plugging, including but not limited to a temperature log. The temperature log will be run over the entire depth of the well and the results will be compared to temperature logs performed before and during CO_2 injection. Generic procedures for plugging wells are described in the COP. Specific plugging procedures will need to be submitted and approved by EPA prior to plugging operations.

CTV states that, prior to plugging, a kill fluid will be "bullheaded" into the wellbore to prevent reservoir fluid inflow and provide a buffer to flush the wellbore. During plugging operations, the cement slurry and displacement fluids will be over-balanced to prevent reservoir fluids from entering the wellbore during cementing operations. The plugging details listed in Table 6 of the COP are consistent with those provided with the abandonment schematic of the Appendix provided in the CBI file with the exception of the slurry volume units. The COP lists the volumes in cubic feet, and the abandonment schematic lists the volumes in barrels (bbl). The conversion between the table and schematic is correct.

The COP states that Plug #1 (bottom-hole cement plug) will cover all perforations and will extend at least 100 ft. above the uppermost perforations, the casing cementing point, the water shut-off holes, or the oil or gas zone, whichever is highest. The bottomhole plug on the plugging schematic is consistent

with perforation depths on the well construction schematic, with the plug extending 100 feet above the elevation of where the packer is to be set. This plug extends into the confining layer sufficiently providing a protective abandonment seal for the bottom plug.

The COP also states that the base of the USDW will be covered by Plugs #2 and #3. If cement exists behind the casing and across the base of the USDW, a 100-foot cement plug will be placed inside the casing across this interface. If the top of cement behind the casing is found to be below the base of the USDW, a cement squeeze will be performed through the perforations. Additionally, a 100 ft cement plug will be placed inside the casing across the freshwater-saltwater interface. However, the application narrative asserts that there is no USDW within the AoR of the CTV 26R project (and therefore does not provide a depth to the base of the lowermost USDW). Based on information in the permit application narrative, the base of the Tulare Formation is between 900 and 1,000 ft. (Based on the aquifer exemption record of decision for the Elk Hills Oil Field, the Upper Tulare—the lowermost USDW—is shallower than 400 feet.) Plug #3, and the corresponding well construction and plugging information may need to be updated accordingly to ensure that the plug extends 100 feet below the base of the USDW.

Plug #4 (the surface plug) will plug the casing at the surface with at least 25 ft of cement.

All cement plugs will be composed of a Class G Portland cement blend that has a minimum 1,000 psi compressive strength and a maximum liquid permeability of 0.1 mD. The applicant states that the cement blend for the plugs will be equivalent to the properties of the Glass G Portland that was used for well construction and is resistant to CO_2.

Questions/Requests for the applicant:

- *Please confirm that the wellbore flushing/bullheading techniques described within the COP will be conducted at rates that will not cause fracturing of the surrounding formations or compromise any plug installation.*
- *The COP details state (on pg. 13) that a 100 ft cement plug will be placed inside the casing across the freshwater-saltwater interface. If there is no USDW, to what layer does this refer?*
- *Please confirm the volume of slurry estimated for abandonment, as the units of measurements (and associated volumes) differ between Table 6 of the COP (in cubic feet) and the abandonment schematic (in bbl).*
- *For completeness, please add the specific surface restoration details (i.e., as described on the well schematics) to the COP Plugging Procedures section.*
- *Please provide a stand-alone document that describes the plugging procedures for attachment to a Class VI permit.*

Monitoring Well Plugging Plan

CTV provided a plugging schematic for each monitoring well in the confidential file of Injection & Monitoring Well Schematics, Elk Hills 26R Storage Project.

For the Etchegoin and Monterey monitoring wells, the schematics include a table with information about the depth of each of four plugs, and the potential method of emplacement (i.e., balanced plug retainer or CT plug). This is satisfactory for this point in the permit process; CTV needs to provide specific

procedures prior to plugging each well. All the monitoring wells are planned to be plugged with Class G cement, which is corrosion resistant and suitable for CO_2 injection projects.

CTV plans to plug the Etchegoin Formation monitoring well with one plug within the surface casing, and three plugs within the long-string casing (including the bottom plug in the Etchegoin Formation). Each of the Monterey Formation monitoring wells will have one plug within the surface casing, one plug within the intermediate casing, and two plugs within the long-string casing (including the bottom plug in the Monterey Formation). The information shown is consistent with the well construction diagrams.

Each schematic indicates that there is no USDW in the area, which will be confirmed during pre-operational testing. The schematics also indicate that casing will be cut to five feet below ground surface, a cap welded to the well, and the land surface will be backfilled and reclaimed.

A plugging schematic is provided for the shallow monitoring well. However, it contains no information about plugging, procedures, the depth of the plugs, the type of cement, or cement emplacement measurement procedure to be used.

Questions/Requests for the Applicant:

- *Please provide information about the plugs for the shallow monitoring well, similar to those for the deeper monitoring wells.*
- *Please provide a narrative description of the plugging procedures for the Etchegoin and Monterey Formation monitoring wells.*
- *Please confirm that surface reclamation will be completed to restore the site to "pre-operation conditions."*